Postregulation technique efficiently supplies multiple output voltages

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Various methods for regulating multiple-output power supplies exist. An emerging technique—secondary-side postregulation, or SSPR—provides advantages for high-frequency, high-power-density dc/dc converters.

Many electronic devices require two or more isolated and tightly regulated voltages. For example, microprocessors require a precisely controlled supply voltage of 3.3V or lower, as well as the traditional 5V supply. Furthermore, electronic products continue to decrease in size, demanding higher power densities and higher efficiency. The combination of these trends presents a difficult challenge for design engineers. Choosing the best approach to generate these multiple voltages requires an understanding of the strengths and weaknesses of available techniques and of how each technique affects an application. The main selection criteria are cost, power-conversion efficiency, and ease of manufacture.

The problem of tight regulation for voltages of multiple-output power supplies is not new. Some of the most popular methods include linear regulators, coupled inductors, post dc/dc converters, magnetic amplifiers (mag-amps), and secondary-side postregulators (SSPRs) with a semiconductor device as a switch. You can describe mag-amps and SSPRs as postregulators with a programmable delay switch. This switch can be a semiconductor device, a saturable reactor, or any other device with switch characteristics. Each of these methods has positive and negative aspects.

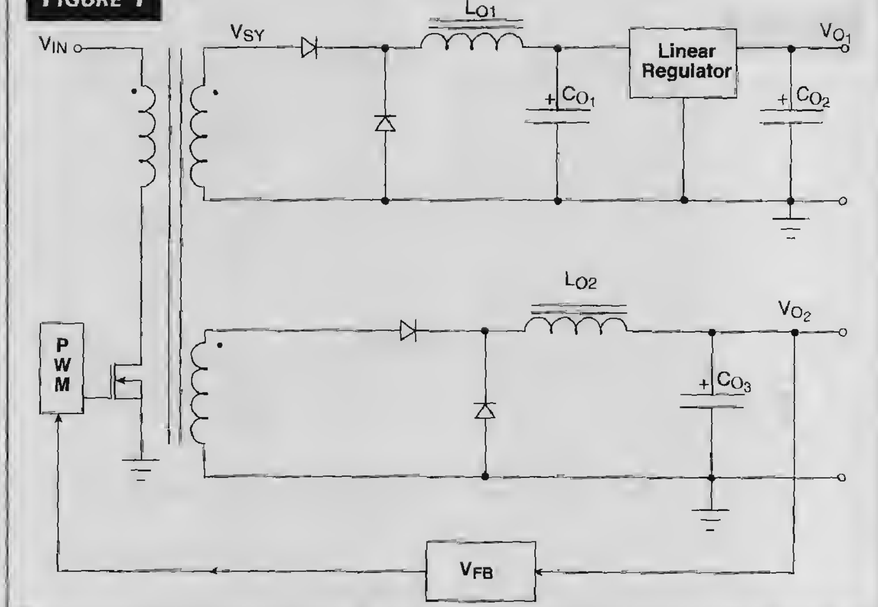
Linear regulators

Linear regulators are the simplest, most straightforward, and most popular approach for low- and medium-current applications (**Figure 1**). These regulators are easy to design in, relatively inexpensive, and widely available. The major disadvantage of linear regulators is relatively poor efficiency. The only way to optimize the efficiency of linear regulators is to provide a tightly regulated voltage at the input of the regulator and to satisfy the minimum dropout voltage conditions at all line and load conditions.

Coupled inductors

Coupled inductors are suitable for regulating secondary voltages for which the tolerance can be ±5% to ±8% (**Figure**

FIGURE 1



Linear regulators are the simplest and most straightforward method of producing multiple outputs and are the most popular for low- and medium-current applications.

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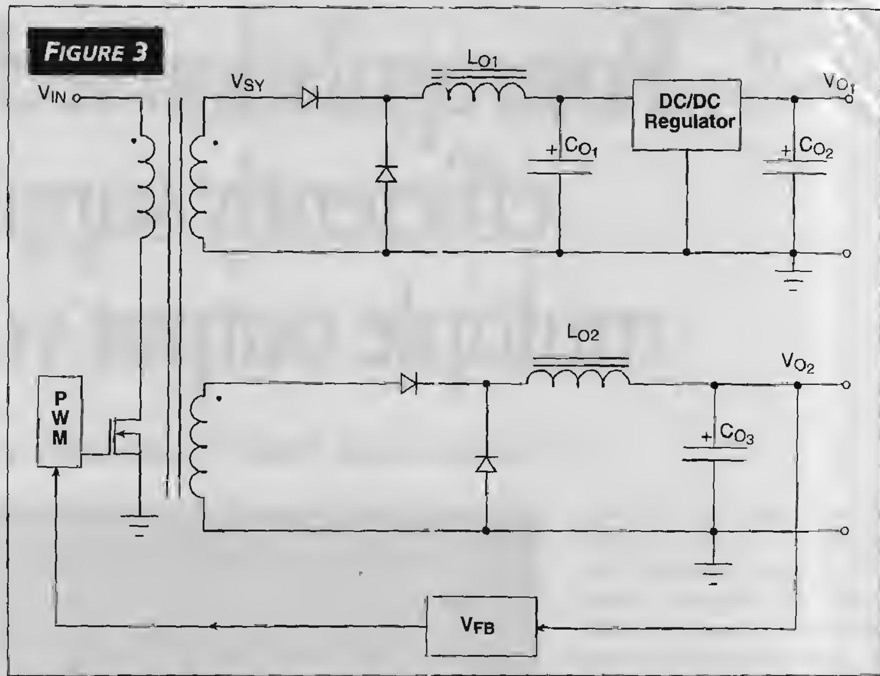
2). Tightly coupled inductor windings provide better regulation. However, tight coupling creates the problem of dynamic interactions between the coupled outputs. Because all outputs use the same inductor, little flexibility exists for component placement, and laying out the pc board sometimes becomes difficult. For any protective or monitoring features, additional circuits are required.

FIGURE 3



Adding a second-stage dc/dc converter, or regulator, to perform postregulation seems simple but presents some design difficulties.

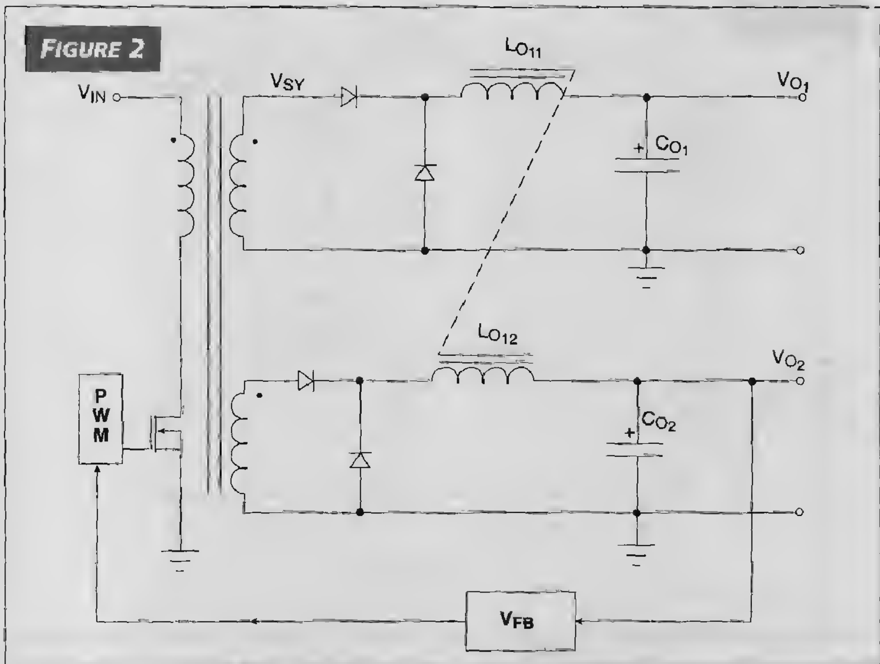
Second-stage dc/dc converters

A second-stage dc/dc converter is another popular method for postregulation. All you have to do is to connect another dc/dc regulator to the existing output (**Figure 3**). However, several potential problems lie behind the apparent simplicity of this technique. First, the output that serves as an input to the second dc/dc converter must carry the combined power of both outputs. Second, an additional ripple current resulting from dc/dc-converter switching action affects the output of the main output, which requires beefing up the output filter with additional capacitors. Third, the second dc/dc converter generates additional ripple and noise and in many cases must synchronize with the main converter, requiring additional circuitry. Fourth, this approach is fairly expensive because it requires an additional set of power switches, inductors, capacitors, and PWM controllers Last but not least, this technique lowers the conversion efficiency because the voltage must be processed twice during the ac-to-dc-to-ac-to-dc conversion.

The function of a magnetic amplifier has nothing to do with magnetic amplification. You could better describe the device as a "saturable reactor." The main component of this regulator is a saturable reactor that acts as a magnetic switch, exhibiting high-impedance characteristics during the blocking period (switch is off) and low-impedance characteristics when in saturation (switch is on) (**Figure 4**).

The two basic types of mag-amps are set and reset. Popular as early as the 1930s and 1940s, the mag-amp approach became popular again in the early 1980s and is probably the most common method for medium- and high-power postregulation. Core materials that exhibit square BH loop characteristics are mainly used for the saturable reactor. In the case of tape-wound cores, cores with very thin tape minimize losses as switching frequencies increase. Unfortunately, 1-mil and thinner tape-wound cores are expensive. With the introduction of so-called "amorphous cores" by Allied Signal (Morristown, NJ) in the mid-1980s, it became possible to use mag-amps at higher frequencies. Still, at 300 kHz and higher, amorphous-core losses are

FIGURE 2

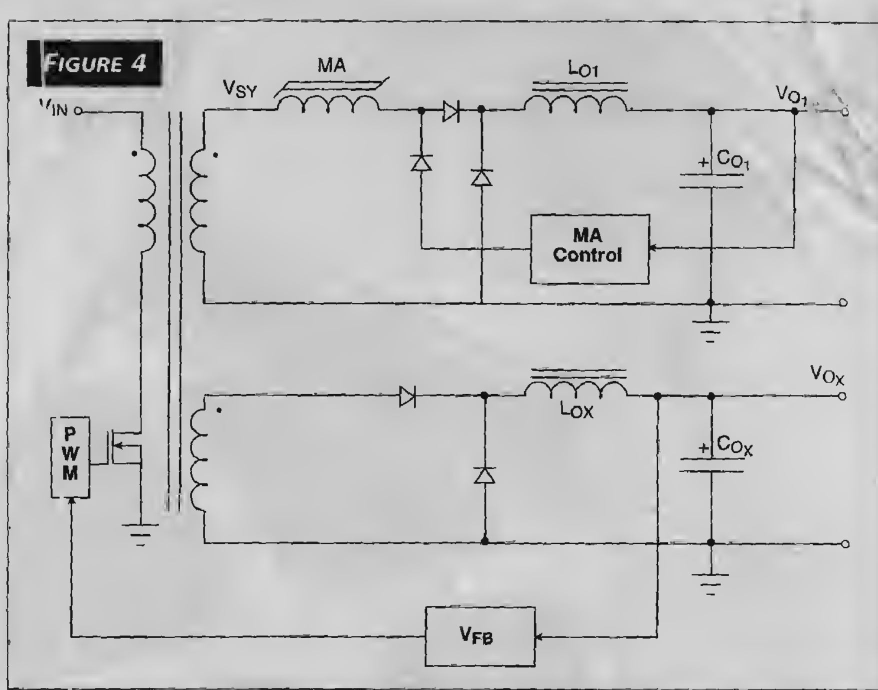


Coupled inductors are suitable for regulating secondary voltages for which the tolerance range is ±5 to ±8%.

high, and designers of high-frequency, high-density dc/dc converters must seek alternative solutions.

The main drawbacks of mag-amps include poor regulation at light or no load. Because the mag-amp must block the pulse during overcurrent or shutdown conditions, the core must be large, increasing both its cost and its losses (high core losses at high frequencies greater than 300 kHz). Finally, except for toroids from a few companies, much manual labor is necessary to wind and assemble a toroid, which also increases the cost.

FIGURE 4



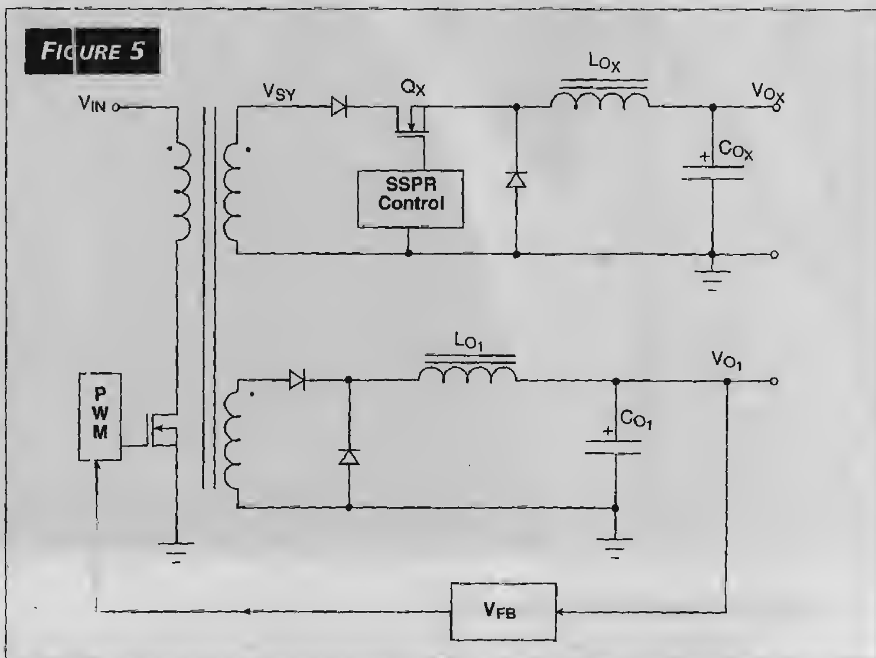
The magnetic amplifier, or mag-amp (MA), is a popular method for medium- and high-power postregulation.

Secondary-side postregulators

An SSPR uses a semiconductor device as a switch. This technique has not been widely publicized, although it has been used in industry for many years. Not until recently, when the requirements for tightly regulated multiple-output dc-dc converters at high frequency (400 kHz) and high-power-density environments became part of everyday design, have the benefits of SSPR been realized.

Early SSPRs required several ICs, several discrete components, and considerable ingenuity on the part of the design engineer. In 1996, Cherry Semiconductor introduced the first inexpensive SSPR-controller IC, and two other manufacturers now also produce ICs for SSPRs (Unitrode (Merrimack, NH) and Linfinity (Garden Grove, CA)). These first-generation SSPR-controller ICs offer combinations of modulation and synchronization techniques. None of these approaches provides an ideal or universal solution, and it remains to be seen if one method will prevail. However, the high efficiency, low cost, and simple implementation of the SSPR technique are rapidly making it the most popular choice for medium-power applications (**Figure 5**).

FIGURE 5



The SSPR technique uses a semiconductor device as a switch. Its high efficiency, low cost, and simple implementation using first-generation SSPR-controller ICs make it a viable choice for medium-power applications.

You can regulate the voltage on the secondary side of the transformer either by controlling the volt-second product across the output inductor for buck-derived topologies or by controlling the amount of energy for boost- and flyback-derived topologies (**Figure 6**). In either case, the power-control device is in series with the appropriate winding and performs either a delayed turn-on function (leading-edge modulation) or a delayed turn-off function (trailing-edge modulation). Both types have many similarities. The transfer functions for both modes are identical except for the negative sign in front of the transfer function for the leading-edge modulation, because the greater the required duty cycle, the earlier the power switch must turn on.

Both methods offer virtually lossless turn-on. With trailing-edge modulation, the power switch turns on before the arrival of the pulse. With leading-edge modulation, the turn-on of the power switch usually happens after the arrival of the pulse. At turn-on, the current in the winding is in steady

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state. The main transformer's leakage inductance determines the time necessary to change this current. As a result of fast-turn-on characteristics of the power switch (usually an n-channel FET), the switch turns on before any measurable change of current in the winding can take place. Thus, turn-on is nearly lossless. Leading-edge modulation offers lossless turn-off as well.

Leading-edge modulation is compatible with any PWM topology and any control method. Trailing-edge modulation creates the current waveform on the primary side with a negative step. Thus, this method is incompatible with peak-current-mode control, which is by far the most popular mode of operation (**Figure 7**).

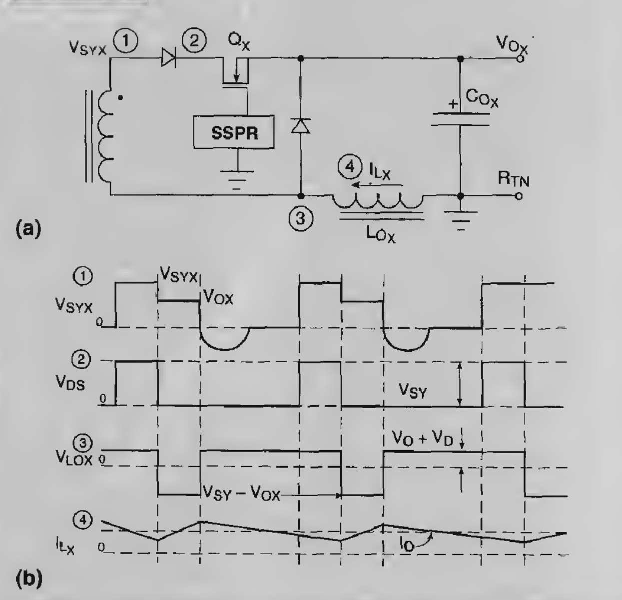
Synchronize to main controller

Another important consideration with SSPRs is frequency synchronization with the main controller. SSPR controllers may have their own oscillators, but an error amplifier and a ramp generator to create the intersection that defines a duty cycle are essential.

The easiest way to accomplish synchronization is by sensing either the leading or the trailing edge of the pulse on the secondary side of the transformer. The advantage of synchronization to the leading edge is that this edge coincides with the start of the switching cycle of the main converter. Secondary effects from this method of synchronization are nonexistent. However, the delay resulting from IC propagation and sensing results in the loss of some available volt-seconds of the pulse. High-frequency dc/dc converters, especially those that derive both 5 and 3.3V outputs from one secondary winding, have tight volt-second budgets. In this case, trailing-edge synchronization is preferable because the entire pulse is available for use.

Note that the main output dictates the trailing edge of the pulse. Thus, the duty cycle varies with changes in the input voltage and load. This variation means that the start of the SSPR ramp voltage also varies, requiring the error amplifier of the SSPR to adapt to these changes to keep voltage in regulation. The most critical situation happens when you subject the main output to step loads. Interaction between major and minor SSPR loops may create transient conditions between the outputs.

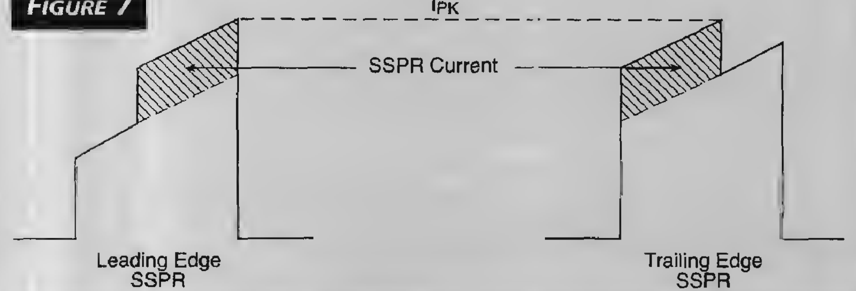
FIGURE 6



When using an SSPR, the power-control device is in series with the appropriate winding (a) and performs either a delayed turn-on function (leading-edge modulation) or a delayed turn-off function (trailing-edge modulation). Waveforms (b) show the circuit's operation.

All multiple-output postregulation methods use some common components to process the pulse. Depending on the method and number of power-conversion stages, different components facilitate regulation of the output. SSPRs that use an n-channel FET as the power switch require only a few low-loss components. The losses of leading-edge-modulation SSPRs are basically the sum of FET conduction losses and losses associated with powering the IC controller and driving the FET. As a result, conversion efficiency greater than 97% is possible.

FIGURE 7



Primary-side current waveforms show the difference between leading- and trailing-edge operation. Leading-edge modulation is compatible with any PWM topology and control method. Trailing-edge modulation creates the current waveform with a negative step, making this method incompatible with peak current-mode control.

Depending on the modulation and synchronization techniques, SSPR controllers can operate in current- or voltage-control mode. Controllers that use voltage-mode control can easily incorporate a feed-forward feature to improve line regulation. Either method lets you achieve load/line regulation in fractions of percentage points. In this tight regulation, SSPR has a clear advantage over mag-amps, which have degrading regulation characteristics at light or no-load conditions.

With each voltage- or current-mode-control method, the main and the secondary loops interact. Thus, designers need to carefully compensate for sta-

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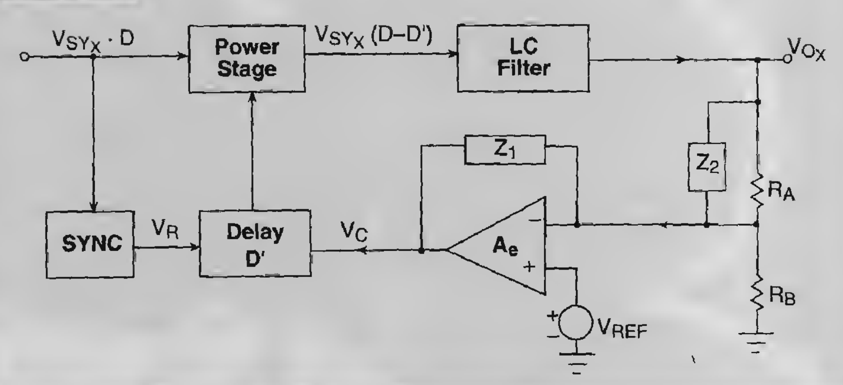
bility. With the peak current-mode control, you should set the crossover frequency of the control loop one decade lower than the main loop's crossover frequency (Figure 8).

One of the most useful features of an SSPR with an n-channel FET as a power switch is that it easily implements shutdown and overcurrent protection. An SSPR controller can incorporate either pulse-by-pulse or average overcurrent protection. In mag-amps, the saturable reactor must be large enough to block the entire pulse, making it larger than regulation requires. Hence, the conversion efficiency is lower, and the cost of the converter is higher.

You can connect an SSPR power switch several ways using both single- and dual-ended topologies. To directly drive the n-channel FET, place a diode between the winding and the FET because n-channel FETs have a parasitic body diode. If you need to use the single-package diode, you need to place the FET in series with the secondary winding and drive the FET through the gate-drive transformer, which adds cost and complexity to the power supply.

FIGURE 8



Loop compensation is necessary because with either voltage- or current-mode control the main and the secondary loops interact.

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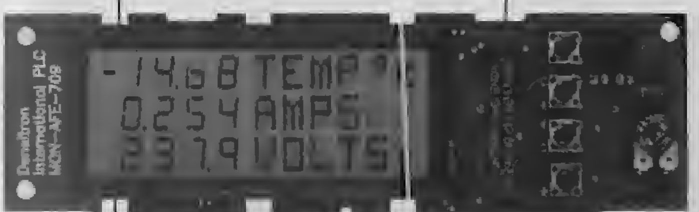

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